New Deposition System for the Microchip Revolution

The team that developed the new precision deposition system. Standing, from left to right, are Jim Folta, Stephen Vernon, Mark A. Schmidt, Gary Heaton, and Richard Levesque. Kneeling are Fred Grabner, Marco Wedowski, Christopher Walton, Claude Montcalm, and George Wells. Not pictured are Gary Howe and Eberhard Spiller.

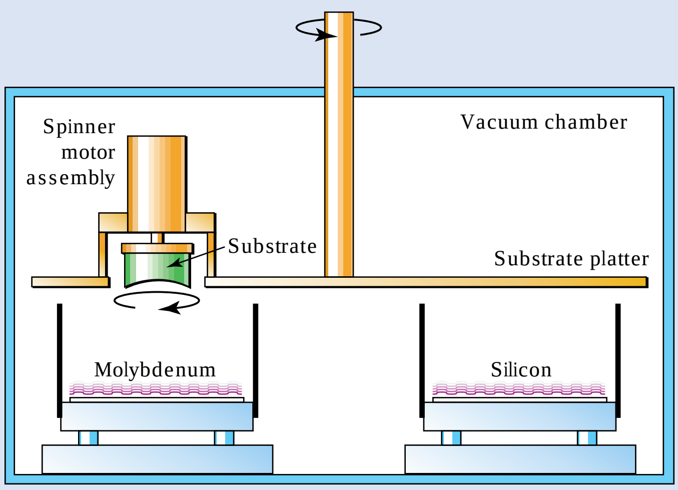
AS silicon microchips become smaller and smaller with more and more information printed on them, they will require improved chip printing methods—current methods will not be usable within the next decade or so. Companies around the world are exploring several next-generation methods, with extreme ultraviolet lithography (EUVL) emerging as the leading candidate. A new invention from Lawrence Livermore is taking EUVL one step closer to reality.

Today, microchips are made by projecting binary circuit patterns onto a photoresist-coated silicon wafer. The size of the features on the chip is limited by the shortest wavelength of light that the lenses in the projector will transmit. When the wavelength is as short as about 140 nanometers, light is absorbed rather than transmitted, so lenses no longer work. Instead, mirrors can be used to reflect the light and allow the use of much shorter wavelengths. With wavelengths at the extreme edge of the ultraviolet spectrum (about 13 nanometers), microprocessor features can be made as small as 30 nanometers. In comparison, the smallest features produced by current lithographic methods are 180 nanometers.

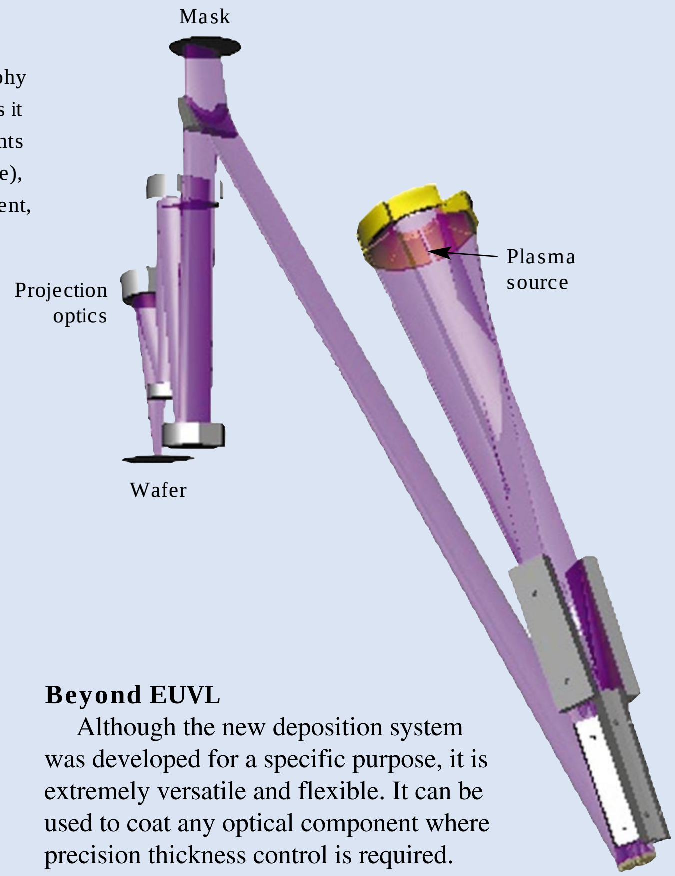
Making a success of EUVL is requiring a number of major engineering and scientific advances. The manufacture of the mirrors has presented a challenge because they must be highly reflective, with surface coatings that are essentially perfectly uniform. Perfect uniformity is difficult enough with a flat mirror, but in EUVL, many mirrors are concave or convex. Nonuniform multilayer coatings destroy the surface figure (shape) of the optics, resulting in distorted lithographic patterns printed on the chips. Until now, the aberrations in the mirrors caused by conventional multilayer deposition systems have been an obstacle to the advancement of EUVL.

But Livermore engineer James Folta and his team have found a way around this problem. They have developed a faster, cheaper, and more precise method for depositing multilayer thin films over large mirrors, whether flat or curved. The system is so precise that 81 alternating layers of molybdenum and silicon, each about 3.5 nanometers thick, can be deposited with the total thickness controlled to within one atom over a 150-millimeter area. The technique can be used to coat mirrors as large as 40 centimeters in diameter.

Emmanuel Lakios, the executive vice president of Veeco Instruments Corporation of Plainview, New York, says enthusiastically, “The Livermore approach to controlling multilayer thicknesses on curved surfaces is truly revolutionary, not only in its ability to achieve atomic-level thickness control, but also in its ease of manufacture.” Veeco is developing a new product based on Livermore’s deposition method.



In the coating system, the substrate platter passes the optical substrate over each sputter source sequentially. The platter velocity is modulated to provide precise control of the radial thickness distribution and absolute film thickness of the coating. The substrate is also spun fast about its own axis for azimuthal (circular) uniformity.



The optical layout for extreme ultraviolet lithography (EUVL) demonstrates the complexity of the optics it requires. The six multilayer-coated optical elements have different sizes, shapes (convex and concave), and prescriptions, each of which requires a different, atomically precise deposition process.

The Extreme Ultraviolet Limited Liability Company, a consortium of Advanced Micro Devices Corporation, Intel Corporation, Micron Corporation, and Motorola Corporation, funds Livermore's work on EUVL. The company also supports EUVL research and development at the Lawrence Berkeley and Sandia national laboratories.

Modulating Velocity

The new Livermore technique produces coatings that can meet the stringent uniformity specification of one part per thousand, a tenfold improvement over conventional vapor deposition processes. Computer software controls the distribution of the coating—whether onto a flat, convex, or concave optic—by modulating the velocity of the optic as it passes through the sputter coating system. (See the figure on p. 12 for a schematic of the system.)

According to Folta, "Being able to precisely modulate the velocity of the optic is the key. With our software, producing uniform or graded coatings on curved mirrors is now as simple as producing the same coating on flat ones and with much more precision than before."

For example, a conventional sputter system running at a constant velocity may produce a coating that is too thin at the edge of the optic. With Livermore's system, the velocity can be reduced as the substrate enters and as it leaves the deposition zones—when only the substrate edges are being coated—to compensate for the nonuniformity. Similarly, the velocity can be adjusted to compensate for curved optics or to achieve graded-thickness coatings with atomic precision.

In its use of computer control, this system also makes a major leap by eliminating the masks used to control thickness distribution. The masks require frequent replacement as uniformity drifts; in contrast, the computer controls readily adjust the velocity "recipe." Software control also allows different coating prescriptions to be achieved on separate optics coated in the same process run. The result is a fast, low-cost, high-performance system. Hardware difficulties have been overcome by software solutions.

Beyond EUVL

Although the new deposition system was developed for a specific purpose, it is extremely versatile and flexible. It can be used to coat any optical component where precision thickness control is required. Examples include lenses used in current-generation lithographic steppers, soft-x-ray space telescopes, optics used on synchrotron beamlines, optical pattern or defect inspection tools, robotic optics for advanced manufacturing methods, and optics for inertial confinement fusion target diagnostics.

The method is broadly applicable to producing coatings from many materials, including metals, semiconductors, and insulators. The flexibility of the approach, stability of the deposition rates, and quality of the thin-film structure combine to make this an extremely effective approach to the production of a large class of coatings.

Optics with multilayer coatings form the backbone of many measuring systems, so the availability of highly accurate, multilayer-coated optics will spawn a new family of measurement tools. But the immediate payoff for this system will be in the advancement of EUVL. Its success will help to ensure U.S. leadership in the next generation of chip manufacturing.

—Katie Walter

Key Words: extreme ultraviolet lithography (EUVL), multilayer coatings, sputter deposition.

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